ROBOTICS COLLABORATION ARMY TECHNOLOGY OBJECTIVE CAPSTONE SOLDIER EXPERIMENT: UNMANNED SYSTEM MOBILITY

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The RC ATO (2004-2008), a joint program between the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and the Army Research Laboratory (ARL), has the mission of developing the appropriate tools, techniques and autonomy to maximize mounted and dismounted control of ground unmanned systems and optimize Soldier-robot and robot-robot teams. This was accomplished through the development and testing of assisted autonomy and situational awareness solutions, optimizing Soldier-machine interface usability across varying display sizes, control devices and dissimilar robotic systems and the deployment of unique multi-modal control techniques. The ATO concluded its Capstone Experiment and demonstration in September 2008. This paper will detail the technology developed and utilized under the program as well as highlight Capstone Experiment results.

INTRODUCTION

General Background

As the emerging technologies of the Army's Future Combat System (FCS) are introduced to the battlefield, Soldiers will increasingly face new challenges in workload management. A shifting force structure will bring increasing responsibilities for the next generation Soldier, who will be tasked with effectively utilizing and protecting robotic assets in addition to performing other primary missions. Our overall program goal is to understand HRI issues in order to develop technologies and mitigations that enhance HRI performance in future combat environments. Tools, techniques, and autonomy are being investigated to maximize mounted and dismounted control of ground and air unmanned systems and optimize Soldier-robot and robot-robot ground and air teams. This includes the development of a scalable user interface for robotic control that maximizes multi-functional Soldier performance of primary mission tasks while minimizing unique training requirements by optimizing and standardizing required interactions and managing workload associated with the control of unmanned ground and air systems.

Unmanned System Mobility

Unmanned system mobility is integral to unmanned systems in a multitude of missions to include Reconnaissance Surveillance and Target Acquisition (RSTA) and convoys. The ability to accomplish military missions while remaining safe (i.e., maintaining secure mobility, McDowell, Nunez, Hutchins, & Metcalfe, 2008), requires force protection measures that address the enemy threat and protect the Soldier

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without sacrificing overall system performance. One cost effective, technically feasible method of increasing force protection for sustainment convoys is the use of autonomous mobility technologies. Autonomous mobility is a technology that enables a vehicle to maneuver across terrain utilizing onboard sensors to interpret obstacles or hazards and plan motion paths without requiring significant human intervention. The development and advancement of this technology has led to usage of robotic vehicles in Future Force concepts (Shoemaker, Bornstein, Myers, & Brindle, 1998). As such, the purpose of the research is to assess aspects of autonomous technologies that facilitate performance in secure mobile operations.

If well implemented, automation of mobility functions during routine convoy operations are expected to enable Soldiers to increase their local situational awareness, provide additional vehicle rest, and/or perform other necessary duties. At a glance, the driving function seems simple: put hands on wheel, orient vehicle on the roadway, maintain adequate speed and avoid objects. Yet, the appearance of simplicity is deceptive. In fact, depending on variations in dynamic contextual factors associated with both the environment and state of the operator, mobility tasks carried out in advanced platforms may impose considerable demands on psychophysical workload and thus, precipitate performance detriments that can be quite dangerous. For example, it has been demonstrated that the high level of workload associated with driving increases the possibility of mistakes occurring even when driving is the only task being performed. Indeed, a nontrivial difference between civilian and military driving is that a civilian driver focuses primarily on safety and mobility whereas the military driver must also devote attention to security. The additional requirement to conduct security scanning tasks while on the move can place extra task demands on the operator (Wickens & Holland, 2000). Ensuring this secure mobility function, defined as the capability of the Soldier-system to traverse terrain in a manner that meets mission demands while sustaining local area awareness (McDowell et al, 2008), is essential to preserving survivability, sustainability and lethality of US military forces. This investigation is aimed at identifying the impacts of the autonomous technologies on Soldier-system performance involving unmanned ground vehicle platforms.

Autonomous mobility is expected to radically change the role of the in vehicle driver and the unmanned vehicle operator; rather than acting as an intensive, active director of the vehicle's movements, the Soldier will become a less intensive observer and supervisor over the autonomous mobility system. The autonomous mobility technologies in manned and unmanned vehicles may potentially increase overall system performance by reducing vehicle operator demands and thus allow simultaneous management of other high value assets or multitasking. Wickens' "multiple resource theory" suggests that concurrent performance of multiple high workload tasks that draw from the same limited resource pool (perceptual and cognitive) can lead to performance decrements due to the non-availability of workload resources (Wickens & Holland, 2000). In a two-operator versus a three-operator manned crew study, it was found that a single operator who actively scans the local environment while driving experienced greater mental workload than an operator only tasked with commanding the vehicle. In-vehicle driving technologies such as anti-lock brakes, electronic stability control, and electric power steering have been used by the civilian automotive industry to improve vehicle handling and subsequently, have been observed to increase vehicle safety in emergency situations where a human would not be able to act quickly enough to avoid dangerous conditions (Sakai, Yoneda, & Shimizu, 2004). Other related technologies, such as drive-by-wire, already have shown clear potential to improve

driving performance, increase crash prevention, and improve vehicle safety (Yih & Gerdes, 2005). These successes support the idea that autonomous mobility and related technologies can be integrated into military platforms to augment the driver's capabilities and improve overall performance.

Autonomous mobility in manned/unmanned ground vehicles can be integrated in several manners. The system could be designed to provide information about potential routes, limit control inputs from the human operator or operate in a collaborative scheme to leverage desirable control capabilities from both human and nonhuman sources (Crandall et al, 2005; Fong et al, 2001; 2003). Supervisory control has potentially the greatest impact on manned vehicle operations and has had success enabling vehicle mobility and reducing operator workload for variety of unmanned vehicles in other hazardous environments (i.e. space exploration, search and rescue following the collapse of the WTC on 9/11). However, Stanton & Young (1998) argued that integrating autonomous components into a system does not necessarily reduce workload; for example, automation can, in certain cases, cause problems with reclaiming vehicle control. Moreover, it has been argued that automation does not remove tasks from the operator but rather, it changes the operator's responsibilities. This shift in operator responsibilities has both costs and benefits (Parasuraman & Riley, 1997). Therefore, despite existence of various methods for integrating autonomous technologies into manned/unmanned vehicles, problems remain in terms of resulting effects on Soldier-vehicle system performance. We will be examining the impact of various mobility technologies on driving performance.

To address these technology concerns, six different autonomous planning driving aids were developed: Confidence, Behavior Levels, Steerable Waypoint, GPS Adjust, Safety Push/Clear Map, and Cost Map. The confidence driving aid is a colored indicator that describes the complexity of the path, speed, cost of the path, and environment. The behavior levels driving aid is a visual and changeable value to increase/decrease the autonomy's maneuvering intensity in the aggressiveness and urgency categories. The steerable waypoint driving aid allows the operator to change the target waypoint by using a controlling device. This will allow the operator to change the long distance waypoint while the vehicle corrects the short waypoints. The GPS adjust driving aid allows the ability such that the operator can shift the current path by some delta in Northing and Easting taking into consideration GPS "pops" (instances where one or more GPS satellites is lost causing a temporary discontinuous jump in reported vehicle position when no such change has actually occurred). The GPS adjust path can be moved which allows the vehicle to plan a new path to this goal. The safety push/clear map is a driving aid that will allow the operator to clear the world model maps. The Cost Map driving aid displays the world map to the operator.

Due to experimental constraint (e.g., experimental control, time, location, etc), only the steerable waypoint driving aid was selected for experimental evaluation.

Unmanned Systems Mobility Experiment Objective

The objective of the unmanned systems mobility research was to quantify the operator performance with the new vehicle control mode technologies developed and to identify technology areas for future performance improvements. This experiment compared three mobility modes (teleoperation, autonomous mobility with teleoperation, and autonomous mobility with steerable waypoint).

METHOD

Participants

Volunteer participants consisted of 13 active-duty Soldiers from the 2nd Combined Arms Battalion 5th Brigade (Army Experiment Task Force) located at Ft. Bliss, TX. All of the Soldiers were male ranging in age from 20-31 with an average of 24 years of age.

Experiment Apparatuses

The driving aids experiment required a manned platform to host the participant and the robotic monitoring and control systems, and an unmanned platform to act as the robotic asset. The manned platform utilized was the Crew-integration and Automation Testbed (CAT – modified prototype Stryker vehicle), and the unmanned platform was the Experimental Unmanned Vehicle (XUV); Figure 1 provides images of both vehicles.

Each vehicle contained a complex suite of electronic equipment for vehicle control, sensing, information exchange, and data logging.

Figure 1. CAT and XUV

Crew-Automation and integration Testbed (CAT). The manned platform used for this experiment was the Crew-integration and Automation Testbed (CAT). The CAT is a Stryker that has been modified for technology integration. There are two crewstations, a Mission Module Work Station (MMWS) and an experimenter station in the vehicle. Each station is comprised of a seat for an operator and a console containing the Soldier Machine Interfaces (SMIs), each of which has video displays and controls to enable the operator to command one or more remote assets or the CAT itself. The CAT can carry up to a crew of five, including a safety driver, experimenter/observer, and three operators (one at each work or crewstation). During the Capstone experiment, the crew consisted of the participant seated at the MMWS, two experimenters seated at another crewstation or the experimenter station, and a trained safety driver who was responsible for CAT mobility and the safety of experimenters and participants inside the vehicle.

Figure 2. CAT Platform and the MMWS

CAT Platform and the MMWS. The multi-mission SMIs support the fight (19K), scout (19D), and carrier (11M) Military Operational Specialty (MOSs) as well as the command and control of unmanned assets. These MOSs and the need for unmanned asset control are the basis of future force manned ground vehicle concept development. Each crewstation generally allows equivalent capabilities and responsibilities and essentially have the same software allowing role-specific (e.g. Vehicle Commander, Driver, or Robotics Operator) assistance. Each crewstation can be configured to support a specific role at any given point in time depending on the mission and task parameters.

Experimental Unmanned Vehicles (XUV). The unmanned platform used in the experiment was the Experimental Unmanned Vehicle (XUV). The XUV was developed under the Demo III program and has similar autonomous mobility systems as the CAT, however, the XUV is smaller, has only 4 wheels, and can also be teleoperated (Figure).

Figure 3. XUV

Multi-Mission Workstation (MMWS). The MMWS was the operational hardware platform used by the participants, and it was located in the rear right side of the CAT. It is an FCS surrogate mission work station used for robotic asset monitoring and control. The Scalable Soldier Machine Interface (SSMI) software provided FCS style displays and controls, allowing participants to interface with the experimental environment via robotic vehicle control devices, a video feed from the XUV camera, and a common operating picture map display.

Subjective Questionnaires. Subjective workload and situation awareness ratings were measured with the NASA-Task Load Index (NASA-TLX, Hart & Staveland, 1987) and the *Cognitive Compatibility Situation Awareness Technique Questionnaire* (CC – SART, Taylor, 1990), respectively. The NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales (Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort, and Frustration). The Cognitive Compatibility Situation Awareness Technique Questionnaire is a subjective rating of situation awareness. Participants rated their experience with the task on three dimensions: Activation of Knowledge, Ease of Reasoning, and Level of Processing. Level of Processing is the degree to which the situation involves, at the low level, natural automatic, intuitive, and associated processing, or at the high level, analytic, considered, conceptual and abstract processing. Ease of Reasoning is the degree to which the situation, at the low level, is confusing and contradictory, or, at the high level, is straightforward and understandable. Activation of Knowledge is the degree to which the situation, at the low level, is strange and unusual, or, at the high level is recognizable and familiar. Workload and situation awareness were assessed at the end of each mission.

The Usability Questionnaire. The Usability questionnaire was administered at the conclusion of all experiment runs, collecting subjective input on the usability of the SMI in general and the steerable waypoint. Responses to individual questions were averaged and using the Likert scale, a percentage of total possible (score) was calculated. An exit interview was also completed at the end of all experiment runs collecting participants' impressions of the system and recommendations for future improvement.

Experimental Procedures

The experiment began with an introduction of the purpose of the RC ATO Capstone experiment. This was a slide presentation that described why autonomous aided technology is emerging and how it works at a mechanistic level. Each participant received this presentation in the beginning of the training process. After the presentation, they received an interactive training session on the System Integrated Laboratory (SIL) located in a closed facility at the Ft. Bliss test site (Figure 1). The SIL is a replicated MMWS with the ability to train the participants in a classroom setting. They were able to become acclimated to the tasks for the experiment, the hardware, software, technology, etc. Participants were able to practice the mobility conditions in the SIL by driving a simulated XUV. The terrain database simulated the Fort Bliss test range, allowing the participants to become familiar with the local terrain.

Figure 1. System Integrated Laboratory (SIL)

The SIL was established on site at the Fort Bliss test range for the dual purposes of conducting participant training and also demonstrating the constructive Soldier in the virtual environment.

During the experimental run (individual mission) the participant operated the XUV from the MMWS in the CAT which was on the move, across approximately 3.3 km at no more than 16 kph using an indirect vision system. Terrain at Ft. Bliss consisted of consisted of arid desert roads with complex sand dunes that had a multitude of vegetation growing on them (see Figure 5).

Figure 5. Ft. Bliss Terrain

The exact route of travel was clearly visible and was provided to the participant. Temporary obstacles (cones and barrels) were placed on the planned route and were set up so as to require the participant to perform various types of pre-planned maneuvers in addition to the general objective of completing the course while staying on the priori path. The maneuvers of interest included placing the Soldiers in situations where they had to alternately avoid an obstacle that the autonomous mobility system should detect, avoid an obstacle that the autonomous mobility system should not detect, traverse a route parallel to the planned path, and stay on the road while navigating a tight corner. The participant was

instructed to traverse the XUV as quickly as possible along the provided route, adhering as closely as possible to the planned route, and avoiding the temporary obstacles as necessary.

Experimental Course Design

The test course featured a series of challenges for the operator and autonomy alike. Several obstacles were placed along the route that would necessitate operator control of the XUV. Figure 6 depicts an overview of the operational test course at the Fort Bliss, TX test range.

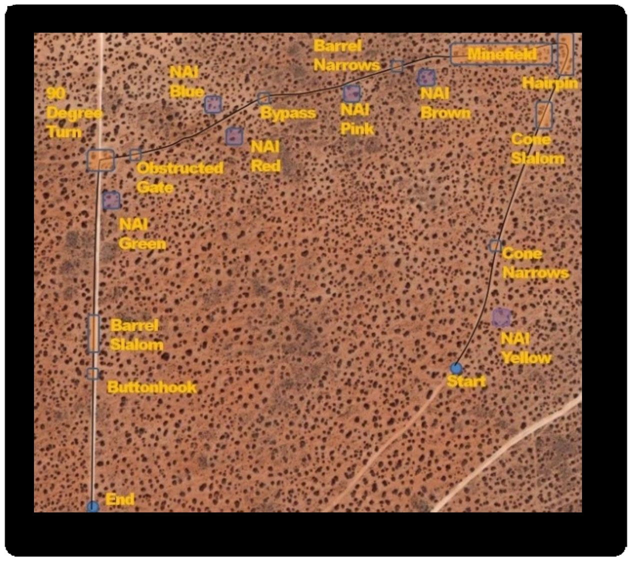

Figure 6. Experimental Test Course

The test course featured ten planned events, or vehicle maneuvers, that an operator faced during a test run. Additionally, the participants were asked to perform reconnaissance of a designated area along the route, based on the specific scenario they were executing.

Several obstacles were created using either cones, barrels, or a combination of both. Traffic cones represented obstacles that were too short for the XUV's Autonomous Mobility System to detect, thus requiring human intervention to avoid collisions. Barrels were large enough to be detected by the XUV Autonomous Mobility System, and thus were considered obstacles that the robot would naturally avoid during its continuous route planning activities while navigating autonomously. For example, the cone narrows measured the ability of the participant to detect and avoid cones while following an a priori route that would otherwise cause collisions between the XUV and one or more cones. The cone slalom measured the ability of the participant to maneuver the XUV in a weaving pattern through a series of cones that were spaced 15 meters apart. Again, the participant was responsible for obstacle detection and avoidance in all test conditions since the cones were too short for the XUV LADAR to sense, and the a priori route would otherwise guide the robot through the middle of the slalom when navigating autonomously. NAI zones were also included to simulate real-time commands to perform reconnaissance off of the a priori route. This tested the Soldiers ability to react to changes in mission without a full vehicle re-planning exercise. In responding to a simulated target of opportunity, participants were required to temporarily deviate from the planned route, read a sign at one of six designated areas, and then return the robot to the a priori route.

Experimental Secondary Task

During each trial, the participant received queries over headphones connected to the intra-vehicle audio mix. These queries assessed the participant's situational awareness of their environment. They received a query approximately once per minute, or approximately 12 per trial. To try and capture how much mental effort it took to navigate the obstacles in the various cases we asked a total of 12 questions. Six of the questions were asked in an obstacle, and the other six were asked in the space between obstacles. A number of questions were generated such that no one question appeared in every scenario.

The queries assessed level 1 (perception), level 2 (comprehension), and level 3 (projection) situation awareness. The participant responded to the queries through the radio. Below are examples of the different levels of situational awareness questions that were asked to the participants.

Level 1 (perception): "What is the current heading of the XUV?"

Level 2 (comprehension): "In which direction did you last deviate from your last route?"

Level3 (projection): "How long until you reach NAI Red?"

Experimental Design

The experiment was a 3x2 within-subject design. The independent variables are mobility condition and time. Mobility condition had three levels: teleoperation, autonomous mobility with teleoperation intervention, and autonomous mobility with steerable waypoint intervention. Thus, the participant completed six missions. The second independent variable was time. Each mobility condition was repeated two times. During the experiment, the participant controlled the XUV with the MMWS.

Teleoperation (TEL). In the teleoperation mode, the participant controlled the XUV through direct control in the MMWS via the joystick as their steering device, and an accelerator and a brake for speed control. Participants directly controlled the XUV throughout the mission in this mode.

Autonomous Mobility with Teleoperation (ATL). In the ATL mode, the participant controlled the XUV through Autonomous Mobility. The XUV was provided an a priori route plan to complete a route through the experimental test course. Once the mission was executed the XUV moved through the terrain without requiring direct control. When an obstacle was encountered the participant was expected to release the XUV from the AM Mode into teleoperation mode and use the direct controls to maneuver through the obstacles. Control of the XUV was then returned to the AM mode.

Autonomous Mobility with Steerable Waypoint (ASW). In the ASW mode, the participant controlled the vehicle in a manner similar to the ATL condition, but using the Steerable Waypoint intervention method instead of teleoperation. The Steerable Waypoint driving aid is a technology that was developed to allow the robotic operator to seamlessly intervene in control that would otherwise be handled by the autonomous mobility system. Steerable waypoint allows the operator to change (or steer) the near-term goal of the autonomy in real-time, rather than requiring the XUV to be stopped and switched into full teleoperation mode (an operation that would have to be done in reverse once the intervention was complete). The waypoint provided when the ASW mode is engaged serves as the goal

for the autonomous system, essentially acting as a "carrot on a stick" and thus replacing the long-range planning point currently being used by the AM system. If the operator places the waypoint directly in front of the vehicle, the vehicle attempts to go straight. As the operator swings the point to one side, the vehicle attempts to turn towards that side. When engaged in steerable waypoint, the operator maintains the ability to control vehicle mobility by instantaneously changing a target waypoint distance from the vehicle (20m to 60m). However, worthwhile to note is the ASW mode differs in an important manner from direct teleoperation. When using the steerable waypoint, the AM system remains engaged and continues to calculate and select the specific path taken between the current and specified location of the XUV. As such, the ASW mode was intended to have the additional advantage of utilizing the safeguarding aspects of the AM system while providing the operator a greater sense of control over the vehicle. In essence, this driving aid was intended to be an advanced version of guarded teleoperation. Figure illustrates the steerable waypoint indicator on the interface. The lower display is the XUV's video; the steerable waypoint overlay is the green cones and lines. The more transparent green cone is the reference point (starting location). The brighter green cone is the location of where the operator is "steering" the waypoint. The lines are indicators for direction from the reference point.

Figure 7. Steerable Waypoint Driving Aid

Dependent Measures

Objective Performance:

To provide the most options for data analysis, all vehicle control variables were calculated within 'performance zones' reflecting a premeditated set of maneuvers designed to assess both advantages and disadvantages of the three vehicle control methods (mobility conditions). Route conformance was calculated from the straight-line differences between the experimentally-observed vehicle position and an 'ideal' trajectory. The ideal trajectory was determined by having an expert operator teleoperate the XUV through a complete run of the experimental course while navigating all obstacles except for the NAIs.

The absolute values of the deviation scores were averaged within each prescribed performance zone and were later aggregated for statistical analysis. Because the speed of the vehicle and the size of each zone varied, this measure of route conformance was based on a different number of observations within each zone than within the other zones on the course. As such, the overall route deviation was based on a weighted mean across all performance zones within participant, run and condition, where the number of data points contributing to each mean was used as the weighting variable.

- *Route Deviation* as measured in mean meters the XUV vehicle deviated from an ideally-driven route over the experimental course.
- *Average speed* calculated by taking the average of the speed over an area.
- *Mission Time* calculated as the time elapsed while the XUV was on the course; defined as the first and last points in time when the vehicle was detected within pre-established start and end boundaries based on GPS coordinates.
- *Number of interventions with the XUV* counted as the number of times the Soldier assumed control of the XUV during the experimental run following a period of time where the AM system was in control (thus, for teleop runs, there was only a single intervention for all participants as the Soldier was in control for the entire time).
- *Time required to intervene with the XUV* calculated as the time elapsed while the Soldier maintained control of the XUV during an intervention epoch, defined as the moment the Soldier assumed control until the moment when he returned control to the AM system.

Subjective Performance:

- *Subjective Workload* was assessed following each mission (experimental run) using the NASA-TLX as described above (section 2.1.1.1.4)
- *Situation Awareness* was probed throughout each mission as described in greater detail below (section 2.1.1.4.6)
- *Interface Usability Survey*, as described above (sees section 0), was administered after the Soldier had completed all experimental runs**.**

RESULTS

Objective Performance

Means and standard errors were calculated for each dependent variable. Mixed linear model analyses were conducted to examine the effects of level of mobility on objective performance, workload, and situation awareness.

Mobility Performance

Results showed that level of automation significantly impacted various facets of mobility performance. Missions were completed faster in the TEL mode than both ATL and ASW.

Mixed linear model analyses revealed a significant main effect of level of mobility on time to complete a mission, $F(2, 32.93) = 86.88$, $p<.00$. Paired comparisons revealed that this main effect was due to the difference in completion times between the teleop and two Autonomous conditions, but the two Autonomous conditions did not differ between themselves. teleoperation mode (1004.16 $\pm$ 27.84sec) was

faster than the other modes and there was no difference in time between ATL (1425.50 $\pm$ 24.50 sec) and ASW (1471.36 $\pm$ 49.08sec), ps<. 01 and ps >.56.

Mobility Performance within Obstacles

Mobility performance was averaged across obstacles. Overall mobility performance varied across mobility level. More specifically, obstacles were completed faster in the TEL mode than both the ATL and ASW. However, halt time was less in the ASW mode than TEL. In addition, route deviation was highest in the ASW mode.

Mixed linear model analyses revealed a significant main effect of level of mobility on time to complete the obstacle, F (2, 33.73) = 26.06 , p<. 00. Additional model analyses for halt time and route deviation showed a significant main effect for mobility level, F (2,18) = 14.33 , p<.00 and F (2, 27.25) = 9.29 , p<. 001, respectively. To resolve the interactions paired comparisons were conducted and showed that all the mobility modes were significantly different from each other for time to complete an obstacle, halt time, and route deviation, , ps<.00. See Table 1 for the mean and standard errors associated with these effects.

Table 1. Mean (Standard Error) Mobility Performance within Obstacles

	TEL	ATL	ASW
Total Time (sec)	19.59(.73)	26.40(1.34)	30.82(1.53)
Halt Time (sec)	.02 (.02)	2.78(.52)	.73 (.32)
Route Deviation (m)	1.21(.09)	1.21 (.05)	2.25(.24)

Table 2 explains the percent of time the robotic operator had to control the driving task of the robot. The autonomous mobility decreases the task of driving by 45% in both situations.

Table 2.Percent of Time in Mobility Modality

Mobility Condition	Teleoperation	Autonomous Mobility	Steerable Waypoint
TEL	100%		-
ATL	53.1%	46.8%	-
ASW	-	45.2%	56.1%

Mobility Performance within the NAI

Mobility performance was analyzed within each NAI. Overall mobility performance varied across mobility level. More specifically, NAI were completed faster in the TEL mode than both the ATL and ASW. In addition, halt times were shortest in TEL mode. Halt times in ASW were longer than TEL but shorter than ATL.

Mixed linear model analyses revealed a significant main effect of level of mobility on time to complete the NAI, F (2, 30.32) = 10.08, p<.00. To resolve the interaction paired comparisons were conducted. Time to complete the NAI was faster in TEL than ATL or ASW mode, p<. 00. Additional

model analyses for halt time showed a significant main effect for mobility level, F (2, 33.93) = 18.16, p<. 00. Paired comparisons revealed that halt time was significantly shorter in TEL than ATL, p<. 00. Further, halt time was significantly shorter in ASW than ATL, p<. 00 (see Table 3).

Table 3. Mean (Standard Error) Mobility Performance within the NAIs

Mobility Condition	TEL	ATL	ASW
Overall Time(sec)	183.59 (14.60)	226.36(15.75)	258.69 (29.43)
Halt Time (sec)	3.01 (1.75)	27.25 (4.10)	10.34 (5.09)

Secondary Task performance: Situation Awareness (SA) Queries

Two aspects of secondary task performance were analyzed, reaction time (seconds) and accuracy for each level of SA. Results for level one and two SA queries showed that level of mobility did not significantly affect performance (reaction time or accuracy) on the secondary task. However, performance on level three SA queries was significantly affected by level of automation. Mixed linear model analyses revealed a significant main effect of level of mobility for reaction time to level three SA queries , F (2, 20.87) = 3.58, p<.04. To resolve the interaction paired comparisons were conducted. Responses to SA queries was faster in TEL than ASW, p<. 02. Further, responses were faster in ATL mode than ASW, p<. 02. Though not significant (p=.09), a similar pattern of result occurred for accuracy on the level three SA queries. Accuracy was higher in TEL mode than ASW (see Table 4) .

Table 4. Mean (Standard Error) Performance for SA Queries

	TEL	ATL	ASW
Reaction Time (sec)			
Level 1	7.38 (.91)	9.41 (.97)	8.99 (1.34)
Level 2	8.18 (1.01)	9.62 (.95)	9.32 (1..7)
Level 3	11.30 (1.46)	8.79 (.57)	12.78 (1.48)
Accuracy Score (na)			
Level 1	.83 (.03)	.81 (.04)	.76 (.05)
Level 2	.74 (.04)	.73 (.05)	.69 (.05)
Level 3	.79 (.03)	.69 (.06)	.68 (.03)

Subjective Performance

Workload

Results for subjective workload showed that perceived performance was poorer and frustration was higher in ASW than TEL mode. Mixed linear model analyses revealed a significant main effect of level of mobility for performance and frustration, F (2, 39.50) = 7.24, p<.00 and F (2, 33.75) = 4.72,

p<.01, respectively. To resolve the interaction paired comparisons were conducted. Performance was lower in ASW than TEL mode and ATL mode, ps<. 01. Similarly frustration was higher in ASW than TEL mode and ATL mode, *ps*<. 01. There was no significant difference between levels of mobility for the other dimensions of workload (See Figure 2).

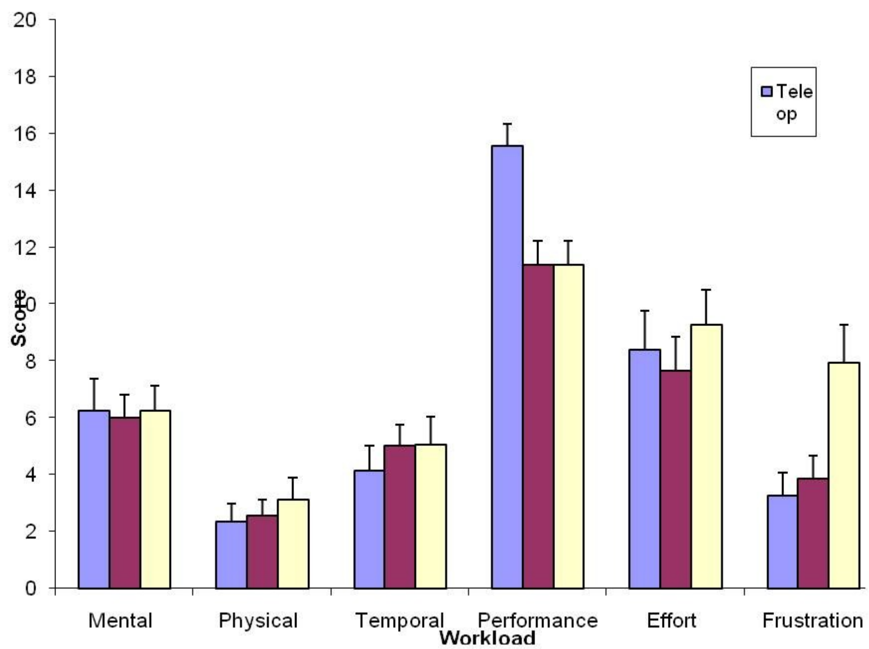

Figure 2. Workload Performance

There were no significant differences between the levels of subjective situation awareness, reported by the CC-SART, between the levels of automation. The lack of significant result may have been due to a lack of understanding of the levels of SA this scale by the participants.

Soldier Feedback

The Usability questionnaire was administered at the conclusion of the experiment, collecting subjective input.

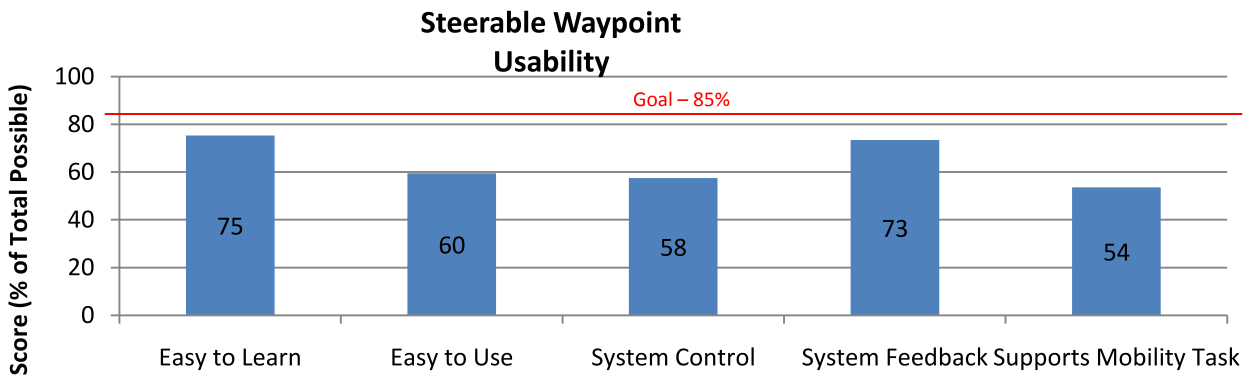

Figure 9. Steerable Waypoint Usability Responses

While the Soldiers responded positively to the steerable waypoint concept, the implementation tested was not regarded as a useful technology, especially when compared to autonomy intervention with teleoperation (See Figure 9). The following exit interview summary captures feedback on the steerable waypoint.

Exit Interview Responses: The exit interview was completed with each Soldier at the conclusion of all experimental runs in an effort to collect impressions of the system and recommendations for future improvement. The exit interview specifically addressed the following topics:

- Autonomous Mobility System (AMS) performance
- Steerable waypoint driving aid performance
- Teleoperation system performance
- Preferences for vehicle control

The Soldier rated overall performance of the AMS a seven on a scale of one to ten, where ten is best. They would all use this system in the field, indicating that it allowed them to multi-task, focusing on other critical mission objectives, such as searching for Improvised Explosive Devices (IEDs) along the route.

Strengths included freeing up time/personnel to complete other tasks, “ease of mind” that the vehicle would stay on course while taking the safest route, and the system’s ability to make its own decisions to avoid obstacles. The Soldier felt the autonomy would be most useful for missions with “a lot of distance to cover” such as convoy operations or as a reconnaissance asset to obtain situation awareness of an area ahead of Soldier.

The Soldiers expressed some concern about the autonomy’s judgment of and reaction to obstacles and the impact course deviations may have on vehicle stealthiness. They often have to make the decision

to go over something the autonomy would likely attempt to avoid in order to maintain a secure/covert route. Large obstacles seemed to result in the vehicle deviating further from the route, "which may give away its position and require a lot of oversight." The Soldiers also had specific concerns about unexpected autonomy behaviors, performance in urban environments, and reaction to water as "water is not seen as an obstacle."

Steerable waypoint performance was rated a four on a scale of one to ten. Four out of thirteen Soldiers stated they would use the technology in a mission "if it was fine-tuned and I didn't have to sacrifice control." The steerable waypoint provided a quick intervention, smoother than the teleoperation transition and allowed "tighter AMS maneuvers." It allowed the controller to influence the autonomy to make tighter turns, nudge the vehicle back on path if it strayed, and control autonomy speed.

The Soldiers used the steerable waypoint to steer the vehicle off course without replanning and to avoid obstacles they thought the autonomy should go through, either based on their assessment of vehicle capability or for concealment considerations.

Overall, Soldiers thought the steerable waypoint concept was good "if it worked." They described "fighting the bot," commenting that it "doesn't do what you want" making it "hard to navigate." All of this required too much concentration and time as the vehicle seemed to stop more often to "think" when the steerable waypoint was used. Soldiers thought the driving aid was more difficult to use and less accurate than teleoperation, which outweighed the benefit of a quicker transition.

Teleoperation system performance was rated a nine on a scale of one to ten and all thirteen Soldiers would use the system in the field. Strengths included complete and reliable control of the vehicle (speed, heading, obstacle avoidance, maneuvers, driving aggressiveness), ease of use, and faster mobility than the autonomy. The Soldiers did not perceive latency in the control system as they did with the small unmanned ground vehicle (SUGV) that they controlled in another Capstone test. Teleoperation would be most useful for missions requiring cover and concealment and in situations where there is not adequate time to create a route plan for the autonomy.

While teleoperation was the preferred AMS intervention method for these test scenarios, the Soldiers did not think that as an individual controller they could adequately multi-task to complete other mission objectives. They would also like to see a more seamless transition from autonomy to teleoperation that does not require many steps or the vehicle to stop. Additional recommended teleoperation improvements included a gimbal (pan/tilt) camera mounted on the vehicle centerline with zoom control and a larger field of view or more cameras placed on the vehicle. The Soldiers also requested a yoke replacement for the joystick.

CONCLUSIONS

Overall, there are beneficial qualities that autonomy can bring to Soldier's performance in respect to workload and reducing interaction time with an unmanned system. Technology was developed to allow for intervention methodologies that create a safe and easy transition of control in the instances that autonomy fails. Steerable Waypoint was the technology developed to do such. In this experiment, the

Soldiers completed a reconnaissance mission using three modes of autonomy. They were responsible for driving the robot and maintaining SA of the mission through embedded communications. In general, they were able to drive the XUV in all the modes tested with minimal training time.

Though the intervention of steerable waypoint was not statistically better than teleoperation or the teleoperation intervention, the potential benefits of an intervening technology was high. The Soldiers requested an easy transition between autonomy and intervention. The teleoperation intervention, while effective and easy to use, required the operator to stop the vehicle, as evidenced by the higher halt times in teleoperation mode than any other mode. The Soldiers requested the ability to transition between teleoperation and autonomy without stopping the vehicle, which they felt would replace the need for and potential benefits of an improved steerable waypoint. Ten of the thirteen Soldiers thought it was easier to intervene with teleoperation than the steerable waypoint due to a "lack of vehicle response" to the driving aid. Teleoperation provided more control and while the transition to teleoperation was "a bit longer, overall the intervention was easier." If the implementation of the steerable waypoint was improved, we are likely to see a significant advantage in mobility and intervention performance.

As with all current and future military systems, training is essential. In this experiment, the training time that the participants received was not sufficient for them to fully understand the critical characteristics of the autonomous system and the driving aid that was developed. They received a half of day's worth of classroom and in-vehicle training. In an actual training session, for a Soldier to become accustomed to a new system, they will spend multiple weeks in a classroom with hands on training before expecting to use the system in a mission style environment. The lack of training was a major contributor to the decline in the participant's performance with the new system, relative to the baseline technologies. The participants got confused about the autonomous vehicle's actions when unexpected events occurred. They did not fully understand how the autonomous system worked nor did they grasp the concept of steerable waypoint. This was evident in the descriptions that were given in the exit interviews. The participants reported that in steerable waypoint there was a "lack of vehicle response". This implies that the participants did not have a clear understanding on how the steerable waypoint worked. Steerable waypoint is designed to allow for an operator to steer a waypoint to a location (20m to 60m in away from the vehicle) and have the AMS do the work to get there. It may react differently than a human's desired path to get to the same location, hence the cause of confusion and frustration levels that were reported in the subjective workload data.

Another concern with automation (e.g., unmanned systems) is the operator's level of trust and the resultant level of use of that automation. A lack of trust in the autonomy may be a contributing factor as to why the steerable waypoint driving aid did not perform as expected. All of the Soldiers had a MOS of 19K; more specifically drivers. Their background in driving (M1 Abrams Tanks) was a cause for concern because of the very specific duties that came along with tank drivers. . They were trained to be in direct control of their vehicle at all times. This was their number one priority in the mission. There was a perceived lack of control when the vehicle was in AM mode. As such, they were confident in the robots location and mission status. They were knowledgeable about the robots status and were able to project about the mission more effectively in the teleoperation and autonomy with teleoperation. Research has shown that while there were circumstances where humans overly rely on automation, there were other equally important instances where they should have relied on automation and did not (see Parasuraman, 2000; Lee and See, 2003). There are two potential strategies that can be used to mitigate this trust issue: Recruit participants with unmanned system or more mission relevant experience. Provide more in depth training to develop the operator's trust in the system.

A secondary task, SA queries, was implemented in experiment 1. Level 3 SA data did not report an increase in AM modes compared to teleoperation. Although autonomy allows the operator to attend

and intervene with the robot less, there is a cost in awareness. In teleoperation the operator is constantly engaged with the robot so when queries about robot state were asked, the queries required less effort to answer. In AM modes, the operator's attention is not constantly on the robot and so when queries were asked that were mostly vehicle related, the operator needed to scan the display more intensely for the relevant information to answer the query. This data suggests that autonomy does have a cost but this cost can be remedied by having the important information that the operator needs to be made more salient.

This data suggests that various modes of autonomy need to be available to the operator. There is no one mode that alleviates the operator from his driving that is perfect in all conditions. A mobility system that has multiple options and is able to provide recommendations to the user on what mode to use in the current terrain may be the best solution. In experiment 1, the Soldiers had minimal understanding of why they needed to use one mode versus another even though they were trained. The experimenters provided cues to the participants during this mission on what mode to use. The higher levels of workload in the AM with steerable waypoint than teleoperation may be due to the operator's frustration with this mode. The lack of understanding of how the technology worked as well as how it was implemented were contributors to the workload levels and performance.

In conclusion, autonomous systems have many beneficial aspects for both manned and unmanned systems. Technology is currently developed that allows an operator to intervene when needed at a faster and easier method. Further research of enhanced methodology of this technology will generate increased performance and likeliness.

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